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Energy Procedia 14 (2012) 1105 – 1110

Energy Procedia

Conference Title

The Energy Efficiency Rebound Effect in China from Three Industries Perspective

Li Li[a,] * , Han Yonglei[a]

[a]Shenzhen Graduate School, Harbin Institute of Technology, Shenzhen, 518055, P.R. China

Abstract

Based on the panel data of three industries in China, this paper calculates the energy rebound effect arising from energy efficiency improvement, by stripping the rebound of energy usage caused by industrial restructuring from model. Results indicate: the similarity between them demonstrating energy efficiency rebound effect as the main component of energy rebound effect; the delayed rebound peak of the secondary industry reflects its lagged respond to changes in energy efficiency; with regard to the peak value in 2009 when calculating the whole nation, author concerns it with the intensification in investment on basic industries and relaxation of restriction over high energy consumption enterprises; the relatively larger value of energy efficiency rebound in China can not be ignored by policy-makers

Keywords: energy efficiency rebound effect, energy intensity, three Industries, industrial structure adjustment;

1. Introduction

Both the issue of global warming and emergence of environment and energy issues in terms of the depletion of primary energy bring the economic development the world over to unprecedented pressure, under which condition low-carbon economy emerges. With the purpose of realizing the sustainable development of energy and economy, nations worldwide are striving to make various low-carbon economy and energy policies, seeking solutions to global warming, and environmental pollution and other traditional issues.

Researches on energy rebound effect, an important concept in energy economy field, are built on the finding that, by Khazzoom (1980) et al 30 years ago, improvement in energy efficiency unexpectedly

* Corresponding author. Tel.: +86-186-658-25548; fax: +86-755-260-33494.
E-mail address: ximlli@yahoo.com.cn.

doi:10.1016/j.egypro.2011.12.887

increases energy usage [1]. Currently, the existence of and effects on energy conservation and sustainable use of energy by energy rebound efficiency are basically confirmed by theoreticians.

Since reform and opening up, industrial structure in China has undergone profound changes. Li Yanmei (2008) proved the significant effect industrial structure exerts on energy consumption in China. Given the disparity in energy efficiency among various industries, energy usage and energy rebound effects change as industrial restructuring. For the sake of revealing the actual energy usage rebound caused by improvement in energy efficiency, this paper explores energy rebound effects in China's three industries, on the context of striping structural effect, and then analyses its trends, providing references for policy-makers.

2. Literature Review

Following Khazzoom (1980), first proposer of energy rebound effect [1], Saunders (1992, 2000a, b), Hens (2009) and other energy experts conducted series studies on this theory [3-6], however by far, there still exists a long way for theoretical researches on energy rebound effect to go.

On the aspect of theory formation path, Grepperud et al (2004) attributed energy rebound effect to reduction in energy cost during production process, in other word decrease in energy price[7]; However, Howarth (1997) pointed out big drawbacks existing in energy rebound research results obtained from models unable to distinguish energy itself or energy service[8]; Berkhout (2000) also took energy rebound effect as the result of energy service, rather than decrease in energy price[9]; yet, after comparative study on improvement in energy efficiency and in energy service efficiency, Saunders (2000) saw pointless in differing energy efficiency and energy service efficiency[4].

According to Zhou Yong (2007), Liu Yuanyuan (2008), rebound effect arises from economic growth caused by technological advances: for one hand, technological advance saves energy by improving energy usage efficiency, for the other, it increases demand for energy by virtue of promoting economy growth, eventually, offsetting the energy saved by improvement in efficiency[10, 11].

Greening and Greene (2000) divided energy rebound effect into three parts: direct effect, indirect effect and economy-wide effect, among which direct effect refers to the offset of energy saving by increase in product and service demand as a result of decrease in prices by improvement in energy efficiency; indirect effect denotes changes in demand for other product or service caused by advances in one energy efficiency; economy-wide effects indicates deep influences on consuming habits, preferences, and consumption structure etc. by advances in energy efficiency[12].

Bentzen (2004) put into use a popular model, Least squares model, to analyze the U.S. manufacturing sector, obtaining the result of about 24% [6]. Jinlong Ouyang (2010) discussed the energy efficiency rebound effect in Chinese household, as part of researches on estimating Chinese Sub-sectors [13].

Contrasted with significant effects obtained by domestic researches, foreign researchers often come to conclusion that energy rebound effect is too small to bother energy policy-makers [6-7, 9]. Taking into account of disparities in energy usage efficiency with developed countries, this paper see the results as objective and representative of the status quo of energy usage in China.

3. Research Method

3.1. The contribution rate of technological advance

Assuming G as the rate of growth, Solow growth model can be expressed as:

$$GY = GA + \alpha \cdot GK + \beta \cdot GL + \gamma \cdot GE \quad (1)$$

Where α , β , γ denote capital, labor and energy flexibility, respectively; *A, K, L, E* represent the

Hicks neutral technological progress, capital stock, labor and energy.

Using to represent the technological advance contribution rate to economic growth, then, we get:

$$\delta = \frac{GA}{GY} = \frac{GY - \alpha \cdot GK - \beta \cdot GL - \gamma \cdot GE}{GY} \tag{2}$$

3.2. The energy rebound effect

Assuming δ_t as the technological advance contribution rate to economic growth in the t year, then we obtain the amount of economic growth caused by technological progress:

$$\delta_t \cdot (Y_t - Y_{t-1}) \tag{3}$$

And the amount of energy consumption arising from technological progress:

$$N_t = \delta_t \cdot (Y_t - Y_{t-1}) \cdot EI_t \tag{4}$$

Where EI_t is the energy intensity in t th year.

Assuming the energy intensity decreases as technology advances, then the amount of energy savings is:

$$M_t = Y_t \cdot (EI_{t-1} - EI_t) \tag{5}$$

Then we get the formula of the energy rebound effect:

$$RE_t = \frac{N_t}{M_t} = \frac{\delta_t \cdot (Y_t - Y_{t-1}) \cdot EI_t}{Y_t \cdot (EI_{t-1} - EI_t)} \tag{6}$$

3.3. The energy efficiency rebound effect

The formula of the energy intensity can be expressed as follows:

$$EI_t = \frac{E_t}{Y_t} = \frac{\sum_{i=1}^{i=3} EI_{it}}{Y_t} = \sum_{i=1}^{i=3} \left(\frac{EI_{it}}{Y_{it}} \cdot \frac{Y_{it}}{Y_t} \right) = \sum_{i=1}^{i=3} EI_{it} \cdot r_{it} \tag{7}$$

Where r_{it} is the ratio of the output of the i th industry to that of the total industry in the t th year.

Therefore, changes in energy intensity can be presented as:

$$\begin{aligned} \Delta EI_t = EI_t - EI_{t-1} &= \sum_{i=1}^{i=3} (EI_{it} \cdot r_{it} - EI_{it-1} \cdot r_{it-1}) \\ &= \sum_{i=1}^{i=3} (EI_{it} \cdot (r_{it} - r_{it-1}) + r_{it} \cdot (EI_{it} - EI_{it-1}) + (EI_{it} - EI_{it-1}) \cdot (r_{it} - r_{it-1})) \end{aligned} \tag{8}$$

In line with the principle of equal contribution and the joint production, we can get the Laspeyres index of the changes in energy intensity and its decomposition model:

$$\Delta EIS_t = \sum_{i=1}^{i=3} (EI_{it-1} \cdot (r_{it} - r_{it-1}) + \frac{1}{2} \cdot (EI_{it} - EI_{it-1}) \cdot (r_{it} - r_{it-1})) \tag{9}$$

$$\Delta EIE_t = \sum_{i=1}^{i=3} (r_{it-1} \cdot (EI_{it} - EI_{it-1}) + \frac{1}{2} \cdot (EI_{it} - EI_{it-1}) \cdot (r_{it} - r_{it-1})) \tag{10}$$

$$\Delta EI_t = \Delta EIS_t + \Delta EIE_t \tag{11}$$

Where ΔEIS_t means the structure share, ΔEIE_t is the efficiency share.

Making $k_t = \Delta EIE_t \ / \ \Delta EI_t$, Energy efficiency rebound effect is:

$$RE_{et} = \frac{N_t}{M_t} = \frac{\delta_t \cdot (Y_t - Y_{t-1}) \cdot EI_t}{Y_t \cdot (EI_{t-1} - EI_t) \cdot k_t} \tag{12}$$

4. Data Sources and Data Processing

4.1. Data sources

•Output data which are represented by national and three industries' GDP data derived from"China Statistical Yearbook 2010", and then conversed based on the fixed price in 1978, in units of 100 million Yuan.

•Capital stock data which are calculated by the perpetual inventory method, in units of 100 million Yuan.

•Labour input data which are presented by economically active population in "China Statistical Yearbook 2010", in units of 10 thousand people.

•Energy input data which also come from "China Energy Statistical Yearbook 2010", in units of 10000 tons of standard coal.

4.2. Data processing

In this paper, the capital, labor, energy flexibility are obtained by the way of fitting C-D production function, C-D production function is shown as follows:

$$Y = A_0 e^{at} K^{\alpha} L^{\beta} E^{\gamma} \tag{13}$$

where $\alpha+\beta+\gamma=1$, Taking the log of formula(13), we get:

$$\ln Y = \ln A_0 + at + \alpha \ln K + \beta \ln L + \gamma \ln E \tag{14}$$

Based on panel data, this paper conducts imitation on the above model, by applying fixed effect model and Eviews software. The model has passed the unit root test, and as to heteroscedasticity problems, weighted least squares method are resorted for; there is no autocorrelation problem in residual serial. Coefficients are estimated as follows:

Table 1. Estimation of production function coefficients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Log(K)?	0.587716***	0.028473	24.90561	0.0000
Log(E)?	0.230725***	0.040612	6.854922	0.0000
Log(L)?	0.181559***	0.060403	3.626756	0.0007

Note: *** represent the significance level of 1%.
Adjusted R-squared is 0.999012.

4.3. Final results

4.3.1. National energy efficiency rebound effect

From a holistic perspective, the energy efficiency rebound effect value varies in every year. There is a cycle in the value of energy efficiency rebound effect from 1997 to 2009, and a peak is reached around 2005, before which the value undergoes an slowly increasing trend and after which it follows a decreasing trend, identical with other literatures.

Before 2005, the value of energy efficiency rebound effect is relatively small, with six-years average of 24.83%; but from 2005 to 2009, the value takes a large scale, with average rising up to 133.33%; except 2003, 2004, the average national energy efficiency rebound effect is 74.18%, almost consistent with the energy rebound effect, indicating the energy efficiency rebound effect as the major component of the energy rebound effect.

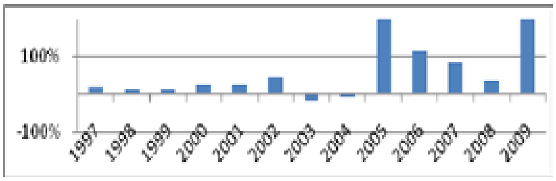

Fig. 1. (a) Results of the nation

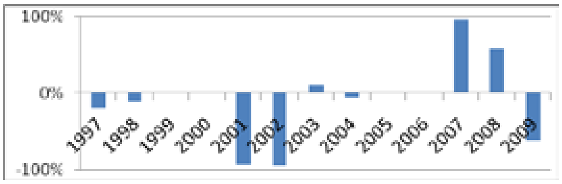

Fig. 1. (b) Results of the primary industry

There is a high bounce in 2009; one possible reason lies in strategies of Chinese government to cope with financial crisis, in terms of increased investment in basic industries, and relaxed controls over high energy consumption enterprises, resulting in a surge in energy usage.

4.3.2. The primary industry energy efficiency rebound effect

The energy usage of the primary industry is subjective to many external factors, in terms of climate change, drought conditions etc., and causing wide fluctuation in agricultural energy usage and output, which contributes to the relatively large value in energy efficiency rebound effect.

During China's speeding up the building of modernization of agriculture from 1996 to 2009, manpower are gradually substituted by machines, making significant increase in energy usage every year, though less changes in terms of output. Hence, as the figure indicates, back fire effect often occurs in energy rebound effect.

4.3.3. The secondary industry energy efficiency rebound effect

Except the negative ones, the average value of the secondary industry energy efficiency rebound effect is 30.36%, smaller than the energy rebound effect, which comes as no surprise, given the fact that energy efficiency rebound effect is the main component of the energy rebound effect.

As the results indicate, the secondary industrial energy efficiency rebound effect also underwent a fluctuation, small and robust. Basic data also displays a robust decline in energy intensity. Energy efficiency rebound effect in the secondary industry is rather convincing, from the perspective that rebound effect comes from rebound in energy usage caused by improvement in energy efficiency.

Different from national, the peak value of the secondary industry arrives in 2006, demonstrating the lagged response to changes in energy efficiency.

4.3.4. The tertiary industry energy efficiency rebound effect

The average value of the tertiary industry energy efficiency rebound effect is 33.00%, much smaller than the tertiary industry energy rebound effect.

As Fig.2 (b) shows, value of energy efficiency rebound effect in the tertiary industry follows the same trend with secondary industry.

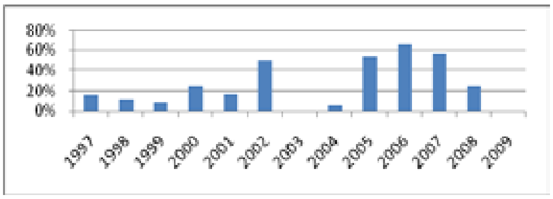

Fig. 2. (a) Results of the secondary industry

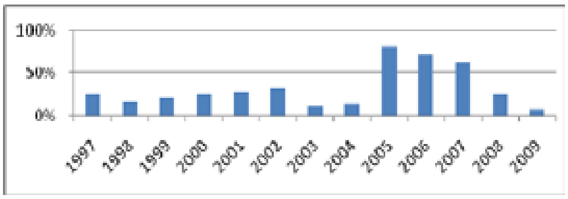

Fig. 2. (b) Results of the tertiary industry

However, differing from other industries, the absent of high bounce in 2009 may be attributed to the less involvement into the intensified investment strategy for the financial crisis.

5. Conclusions and Discussion

To sum up, the energy efficiency rebound effect is less than energy rebound efficiency, no matter on national or three industries' level, revealing the existence of other factors, except improvement in energy efficiency, in contributing to energy usage rebound. The results of our calculation bear an analogy with that of other domestic literatures, slightly higher than that of foreign calculations, suggesting room for improvement of energy efficiency in China, as well as the incapability of the foreign prevailing conclusion that "energy rebound efficiency value is too small to bother energy policy-makers" to Chinese situation.

Energy efficiency rebound effects in national and the last two industries' exhibit analogous trend, in other words, they all reach the peak value in 2005 and 2007, after a slowly increasing trend followed by a declining trend. Difference occurs in secondary industry, which reaches a peak value in 2006, one year lagging behind national and other industries' arrival in 2005, revealing the slow reaction to improvement in energy efficiency of secondary industry.

The wide fluctuation of energy efficiency rebound effect in the primary industry reflecting that energy usage in primary industry are strongly subjective to weather and other factors. Energy efficiency rebound effect in the secondary industry is relatively robust, indicating its continuing improvement in energy usage efficiency, and its relying on energy. In the light of similarly domestic literatures, energy rebound effect in the tertiary industry is slightly less than that of the secondary industry, while as far as energy efficiency rebound effect is concerned, results from this paper display the opposite situation, demonstrating the sensitivity of the tertiary industry to changes in energy efficiency, which cause greater flexibility in energy usage; hence, compared with the secondary industry, the tertiary industry responds more quickly.

Results of this paper unveil different characteristic in energy usage among industries, which can serve as reference for energy policy-makers.

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